



# Introduction to Synthetic Biology



Topic 1

Topic 2

Topic 3

Topic 4

Topic 5

## Foundations for Synthetic Biology

Vincent Rouilly  
Bioengineering Department  
Imperial College London





# Introduction to Synthetic Biology



Topic 1

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## Standard for Physical DNA Composition

Vincent Rouilly  
Bioengineering Department  
Imperial College London





# Introduction to Synthetic Biology



Topic 1

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## Standards for Functional Composition

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Bioengineering Department  
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# Introduction to Synthetic Biology



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## Characterising Biological Parts

Vincent Rouilly  
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# Introduction to Synthetic Biology



Topic 1

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## Building Systems from BioBricks

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# Introduction to Synthetic Biology



Topic 1

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## Foundations for Synthetic Biology

Vincent Rouilly  
Bioengineering Departement  
Imperial College London

Press Review

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# Press Review

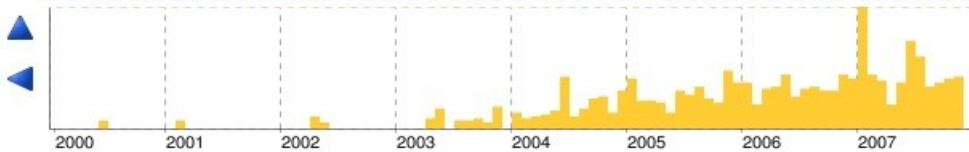
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### [Scientists Call For Global Push To Advance Research In Synthetic...](#)

Science Daily - Science Daily (press release) - Jun 26, 2007

That research area is **synthetic biology** – the construction or redesign of ... **Synthetic biology** offers solutions to these issues: microorganisms that ...

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### [Synthetic Biology? Memory In Yeast Cells Synthesized](#)

Science Daily - Science Daily (press release) - Sep 17, 2007

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# Press Review: Main Stream

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Some think bank with tradition.  
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**Synthetic biology**

**Life 2.0**

Aug 31st 2006 | BERKELEY, CAMBRIDGE

From *The Economist* print edition

**The new science of synthetic biology: its time will soon come**



**Forbes**.com

**Architect of Life**

Matthew Herper 10.02.06

Drew Endy aims to reinvent the biotechnology industry.

To Drew Endy, all the great breakthroughs in biotechnology of the past century—their successes and failures—were simply the result of moving forward, one step at a time, using this genetic data. If he succeeds it will change the way mankind interacts with the living world.

The 36-year-old professor at Massachusetts Institute of Technology is using synthetic genetic material, much as bits of mortar or silicon are used to build structures. These wonderful living objects that make copies of themselves, to create new life.

In coming years, Endy says, we'll begin to see the first custom-built cells. These "devices" will guard against disease, create new medicines. In very early days; scientists do not know how to build such devices yet.

Endy, along with three synthetic-biology comrades, started a company called Codon in 1999, with \$13 million in backing from Flagship Ventures and three other firms. Codon intends to produce its own creations, but that accomplishment is still a long way off.

Initially Codon's goal is to dominate the gene-synthesis market. The company recently shipped the biggest piece of DNA ever made, a hunk of 100,000 base pairs.

Codon claims it will have more production capacity by year-end 2006 than any other company in the world, and DNA 2.0, founded in 2003, both of which also deliver DNA.

**Economist.com**

**Synthetic biology**

**Playing demigods**

Aug 31st 2006  
From *The Economist* print edition

**Synthetic biology needs to be monitored, but not stifled**

THERE will be no thunderstorm, no bolts of lightning channelled through giant switchgear, and definitely no hunchbacks called Igor. But sometime soon a line will be crossed in a laboratory somewhere and the first unarguably living thing created from scratch by the hand of man will divide itself in two and begin to reproduce. When it does so, it will abolish, once and for all, a distinction as old as human thought: that between animate and inanimate matter.



It is not considered polite, in the circles of synthetic biology as the subject is known, to mention the "F" word. Yet behind almost every discussion of the ethics of modern biology lurks the grinning spectre of Mary Shelley's novel, "Frankenstein", a parable on the unintended consequences of creating life. In truth, there is not much that is ethically dubious about making a bacterium from scratch. Making life is less worrying than modifying life—and modifying it in ways that are accidentally or deliberately harmful to mankind.

Synthetic biology is more than the mere tinkering of biotechnology. That just moves single genes around. Synthetic biologists plan to move lots of genes and to industrialise the process in a way that will let people order biological parts as routinely as they order electrical components. If this vision is realised (and there is still a long way to go) biotechnology will become a true branch of engineering, with benefits for industry, medicine and agriculture (see [article](#) and [article](#)). But biotechnology will also become a game that almost anyone can play—for fun or profit; recklessly or responsibly; for good or ill.



# Press Review: Science/Tech

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October 23, 2006

## FEATURE ARTICLES June 2006 issue

### BIOTECHNOLOGY

## Engineering Life: Building a Fab for Biology

Principles and practices learned from engineering successes can help transform biotechnology from a specialized craft into a mature industry  
By The Bio FAB Group

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Although the term "gene  
decades, and recombina  
research, most biotechn  
engineering. One reason

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## Life, Reinvented

A group of MIT engineers wanted to model th

## Designs on life

Earlier this month, students from around the world locked horns in competition. Their challenge was to build functioning devices out of biological parts. **Erika Check** finds out how they got on.

Even if you're thinking big, you usually have to start small. Especially, as a group of Swiss students found, when big means counting to infinity. The team was drawing up a blueprint for the world's first counting machine made entirely of biological parts. Although they had their sights on billion numbers, they opted to go no higher than two. If the plan worked, it would be a proof-of-principle for a much larger tallying device.

The group, from the Federal Institute of Technology (ETH) in Zurich, was one of 17 teams unveiling their projects at the first international Intercollegiate Genetically Engineered Machine (iGEM) competition, held at the Massachusetts Institute of Technology (MIT) in Cambridge on 5 and 6 November. The event attracted students from all over the world to design and build machines made entirely from biological components such as genes and proteins. They drew up grand designs for bacterial factories, photosynthetic lights, thermometers and sensors. And if none of the designs succeeded completely, that was more because of the limitations of the nascent science of synthetic biology than any lack of enthusiasm, creativity or hard work.

Synthetic biology aims to merge engineering approaches with biology. Researchers working at the most basic level are copying simple biological processes, such as the production of a protein from a gene. They break the process down into its component elements, such as a gene and the pieces of DNA and other molecules that control its activity. They then string these elements together to build a machine. They know, of course, in a particular way — an on-off, between producing and not producing, protein or protein or protein that can switch a single molecule on or off.

It is this kind of component — on/offers and switches — that engineers older from computers and built together into a more complex circuitry of bits and bytes. Synthetic biology is trying to develop a similar amount of biological components. And if it does, that could be a great thing. Genetic circuitry could be used to build a machine that can be ordered and plugged into a cell, as a memory and transducer can be ordered and plugged into electronic circuitry.

The first synthetic circuit was created and introduced in a host of ways, including engineering. Instead the development of this new science. No, the new engineers, the leading scientists, feel



Bidding for glory: teams from the ETH in Zurich (top), Cambridge, UK (bottom right) and Massachusetts at the first international Intercollegiate Genetically Engineered Machine competition.

from the ground up. Instead, they have constructed a framework for engineering the cell, the state-of-the-art competition. The iGEM event began in a project leader, MIT students in 2003. Last year, it was the first time to other US universities, and this year, it went international. The organizers hope to attract 50 to 100 teams to the event, including some from Asia.

### Competitive culture

Most of the teams competing in the event are students' teams, so the winning team, the MIT team, has the prize of a \$10,000 award. The team is also the first to win something from the event. "It's a great honor to be the first to win something from the event," says the MIT team's leader, David Liu, who organized the competition. "It's a great honor to be the first to win something from the event."

Nature, Nov 2005

Biologists are crafting libraries of interchangeable DNA parts and assembling them inside microbes to create programmable, living machines

## SYNTHETIC LIFE

By W. Wayt Gibbs

Evolution is a wellspring of creativity. 3.6 billion years of mutation and competition have endowed living things with an impressive range of useful skills. But there is still plenty of room for improvement. Certain microbes can digest the explosive and carcinogenic chemical TNT, for example — but wouldn't it be handy if they glowed as they did so, highlighting locations of buried land mines or contaminated self-Wormwood shrubs, generate a potent medicine against malaria in burly immune systems that are expensive to extract. How many millions of lives could be saved if the compound, arsenite, could instead be synthesized cheaply by vast swarms of bacteria? And although many cancer researchers would trade their eyes for a cell with a built-in, easy-to-read counter that ticks over reliably each time it divides, some apparently have not dreamed such a thing. It could be a game-changer in the world.

one species to another for 30 years, yet genetic engineering is still more of a craft than a mature engineering discipline. "Say I want to modify a plant so that it changes color in the presence of TNT," says Drew Endy, a biologist at the Massachusetts Institute of Technology. "I can start tweaking genetic pathways in the plant to do that, and it'll be lucky, then after a year or two I may get a device" — one system. But doing that once doesn't help me build a cell that swims around and can plaque from artery walls. It doesn't help me grow a little machine, basically the current practice produces pieces of art."

Endy is one of a small but rapidly growing number of scientists who have set out in recent years to harness the foundation of genetic engineering with what they call synthetic biology. They are designing and building living systems that behave in predictable ways, that use interchangeable parts, and to some extent, to make genetic engineering worthy of its

Scientific American, May 2004

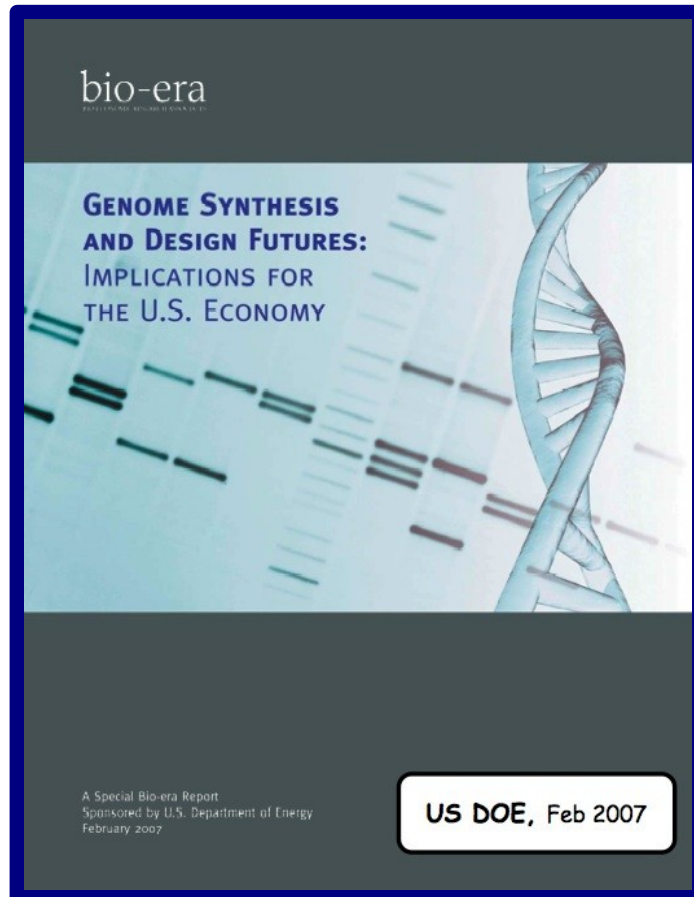
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## Just What Is Synthetic Biology?



# Press Review: Govt Institutions





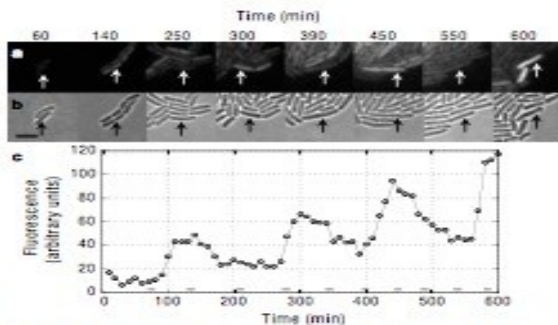
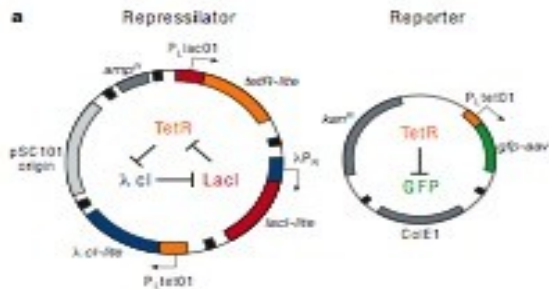
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## A synthetic oscillatory network of transcriptional regulators

Michael B. Elowitz & Stanislas Leibler

Departments of Molecular Biology and Physics, Princeton University, Princeton, New Jersey 08544, USA



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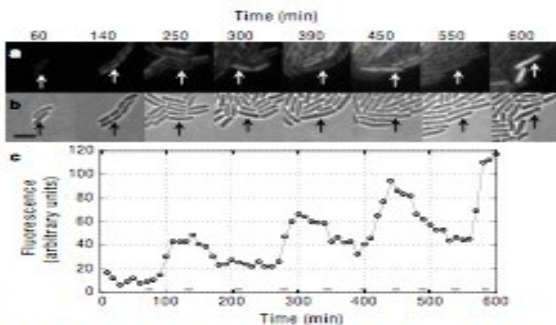
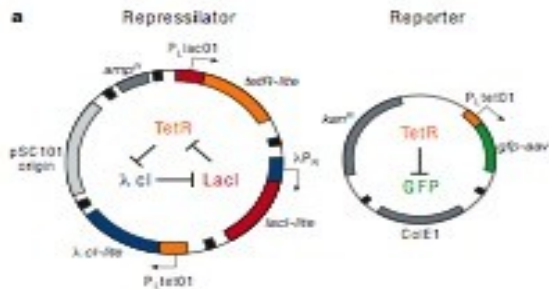
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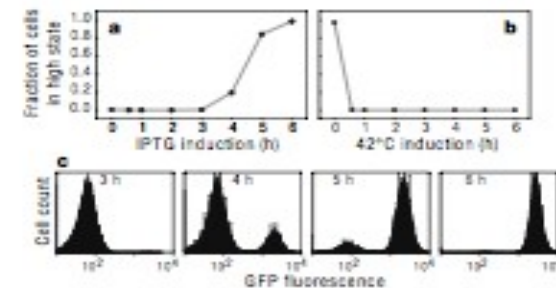
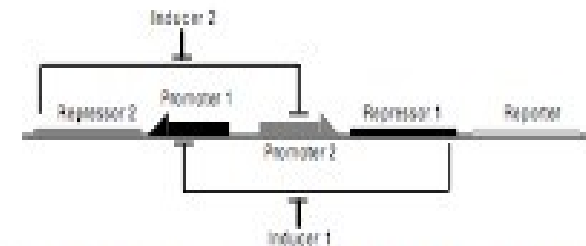


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## Construction of a genetic toggle switch in *Escherichia coli*

Timothy S. Gardner<sup>\*</sup>, Charles R. Cantor<sup>\*</sup> & James J. Collins<sup>††</sup>

<sup>\*</sup> Department of Biomedical Engineering, <sup>†</sup> Center for BioDynamics and <sup>‡</sup> Center for Advanced Biotechnology, Boston University, 44 Cummings Street, Boston, Massachusetts 02215, USA



year 2000



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A Levskaya, AA Chevalier, JJ Tabor, ZB Simpson, LA ... - Nature, 2005 - [ncbi.nlm.nih.gov](#)  
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... Nature Reviews Genetics 7, 242-243 (April 2006) | doi :10.1038/nrg1844. **Synthetic biology**: Building up a picture of gene regulation. Magdalena Skipper. ...  
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EL Leong, DJ Dwyer, JJ Collins. Nat Biotechnol. 2005. [ncbi.nlm.nih.gov](#)

Nature

PNAS

Biotechnol.

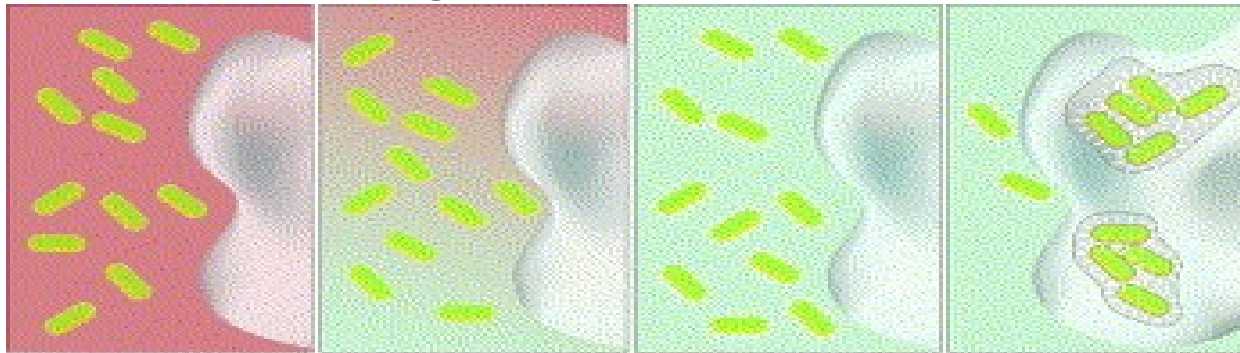
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# Current Research: Biomedical

## Tumor-Killing Bacteria, JC Anderson et al, 2004.



Aerobic  
Conditions  
Low Cell  
Density  
OFF

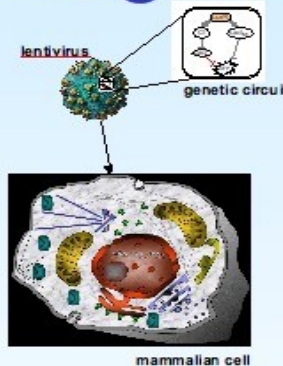
Hypoxia  
High Cell  
Density  
ON

inv  
Induction

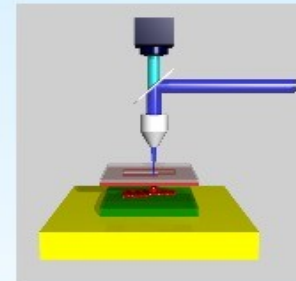
Invasion

## Programmed Tissue (Re)generation

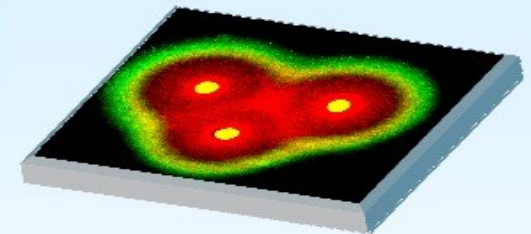
Ron Weiss' Lab, Princeton.



Step #1:  
genetically engineer  
new communication &  
differentiation pathways



Step #2:  
Laser Direct Write\*  
of cells onto a  
substrate

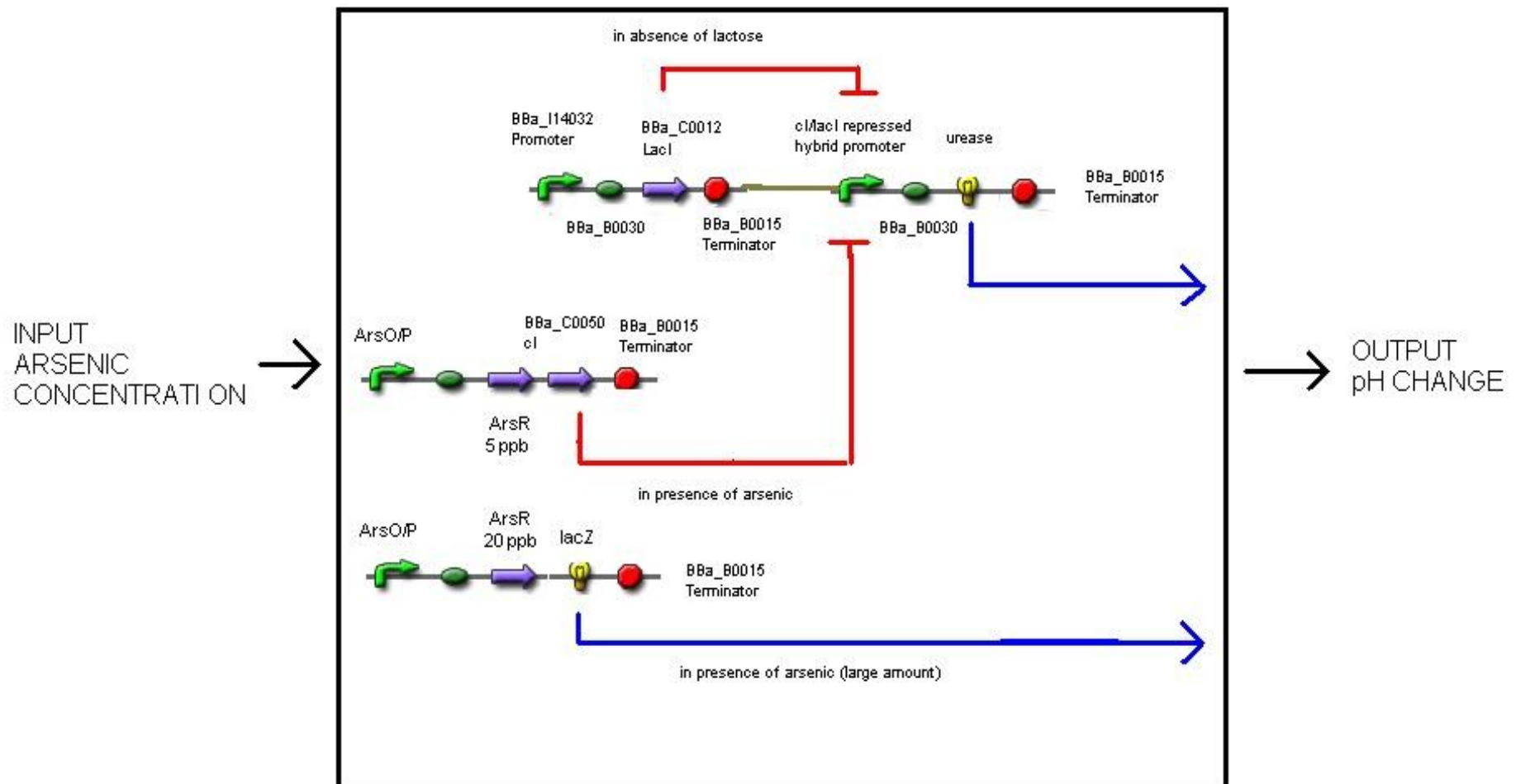


Step #3:  
pattern formation and tissue  
generation based on engineered cell-  
cell communication

\* Collaboration with Craig Arnold's Lab



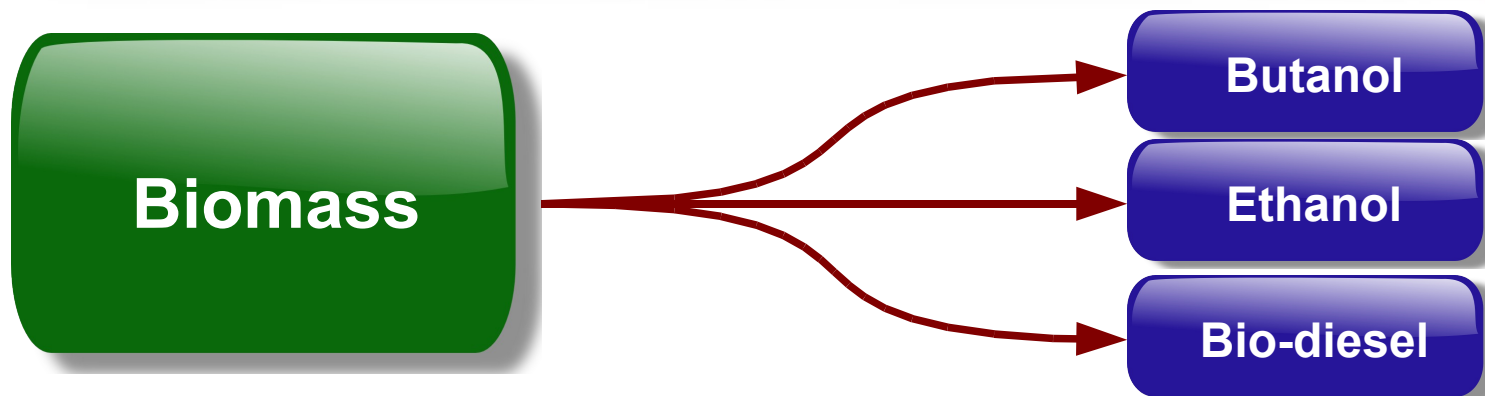
# Current Research: Environment



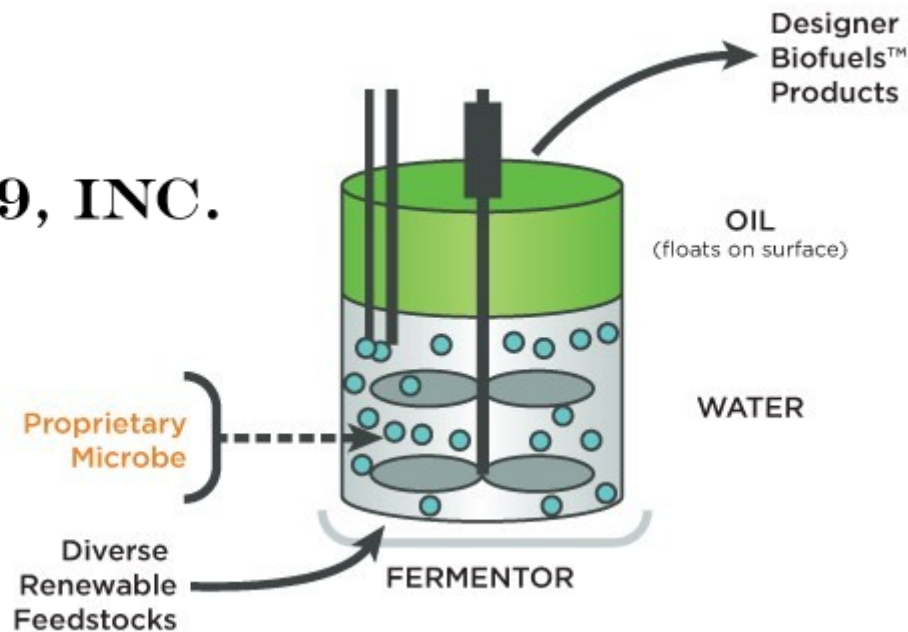
**Arsenic Biosensor, iGEM 2006, Edinburgh Team**



# Current Research: Bio-Energy



LS9, INC.





# Current Research: Drug Development

## Bacterial drug factories

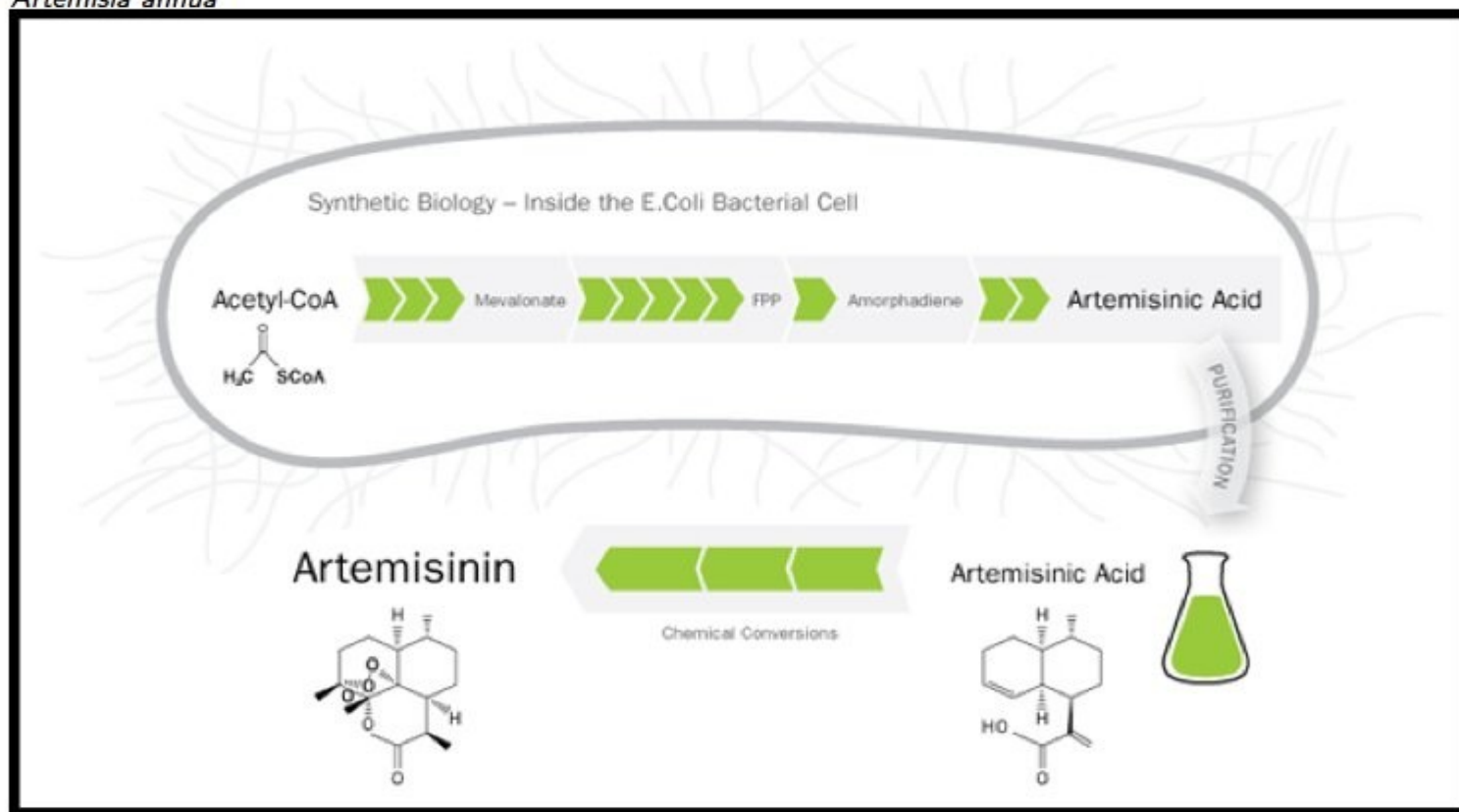


AMYRIS  
BIOTECHNOLOGIES



Institute for OneWorld Health  
A Nonprofit Pharmaceutical Company

*Artemisia annua*

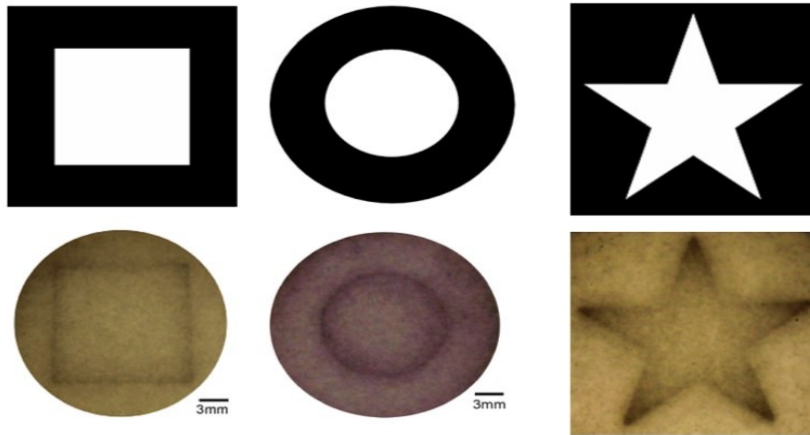


\* from Austin Che's presentation



# Current Research: Information Processing

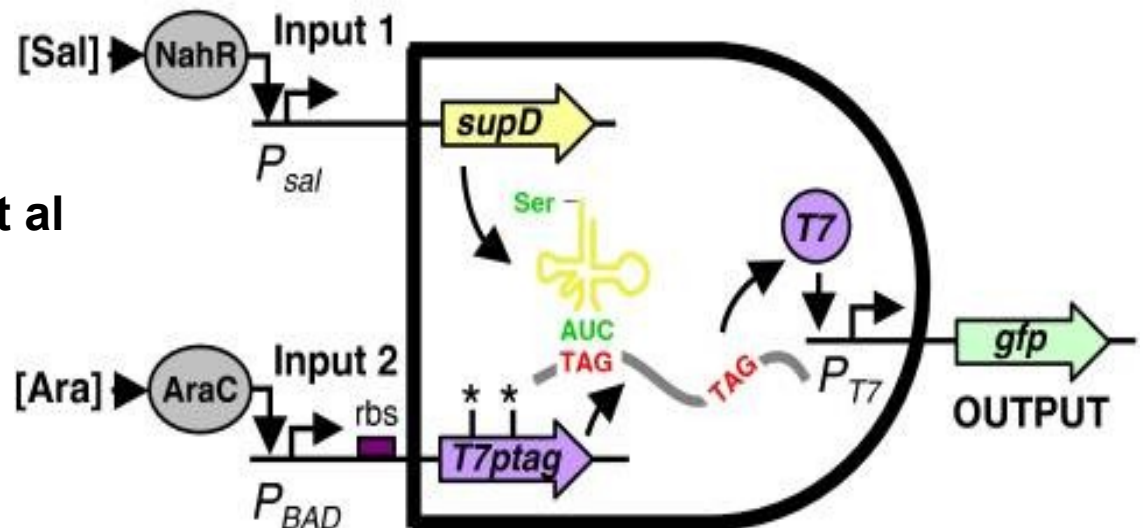
Bacterial signal processing for edge detection



Jeff Tabor

“Bacterial Edge Detector”, Jeffrey Tabor

“AND Gate”, JC Anderson et al







# Synthetic Biology Definition



...





Defined by its areas of application ?

**Biology**

**Synthetic Biology**

**Bio-Energy**

**Bio-Materials**

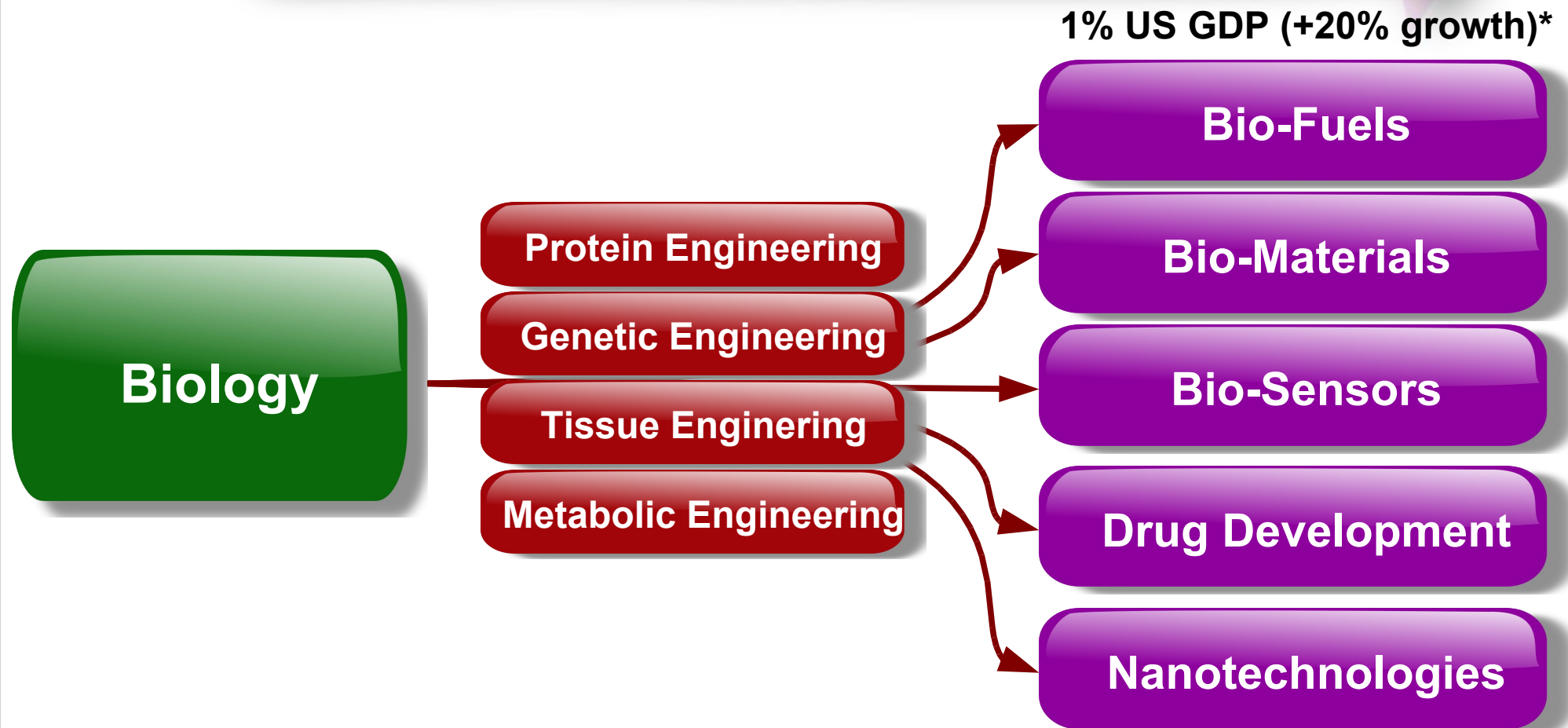
**Bio-Sensors**

**Drug Development**

**Nanotechnologies**



# Defined by its areas of application ?



\* Carlson, 2008.





Defined by its technological platform ?

## Synthetic Biology Toolbox

Recombinant DNA  
Cloning – Directed Evolution

DNA Sequencing  
DNA Synthesis

High-throughput technologies  
(NMR, micro-arrays, automation)

Computational  
Modelling



# Defined by its technological platform ?

## Synthetic Biology Toolbox

Protein Engineering

Tissue Engineering

Genetic Engineering

Metabolic Engineering

Recombinant DNA  
Cloning – Directed Evolution

High-throughput technologies  
(NMR, micro-arrays, automation)

DNA Sequencing  
DNA Synthesis

Computational  
Modelling



## Synthetic Biology

**Synthetic Biology is**

- A) the design and construction of new biological parts, devices, and systems, and
- B) the re-design of existing, natural biological systems for useful purposes.

(Español)





## Synthetic Biology

**Synthetic Biology is**

- A) the design and construction of new biological parts, devices, and systems, and
- B) the re-design of existing, natural biological systems for useful purposes.

(Español)



**Protein Engineering**

**Tissue Engineering**

**Genetic Engineering**

**Metabolic Engineering**





# iGEM Perspective



**iGEM** - The international Genetically Engineered Machine competition



**iGEM addresses the question:** Can simple biological systems be built from standard, interchangeable parts and operated in living cells? Or is biology simply too complicated to be engineered in this way?

[www.parts.mit.edu/wiki](http://www.parts.mit.edu/wiki)



# iGEM Perspective

**iGEM** - The international Genetically Engineered Machine competition



iGEM addresses the question: Can simple biological systems be built from standard, interchangeable parts and operated in living cells? Or is biology simply too complicated to be engineered in this way?

[www.parts.mit.edu/wiki](http://www.parts.mit.edu/wiki)

## True Engineering Approach to Biology

**Standard**

**Interchangeable**

**Parts**

**Protein Engineering**

**Tissue Engineering**

**Genetic Engineering**

**Metabolic Engineering**





# Engineering Approach



## Industrial Revolutions

### Mechanical

Machine Tool

Nuts & Bolts

### Transport

Trains

Car / Road

### Chemical

Large scale  
production

### Digital

Hardware

Communication  
protocols

File Format





# Engineering Approach



**Abstraction**

**Standardisation**

**Quality Control**

**Industrial Revolutions**

**Mechanical**

Machine Tool

Nuts & Bolts

**Transport**

Trains

Car / Road

**Chemical**

Large scale  
production

**Digital**

Hardware

Communication  
protocols

File Format

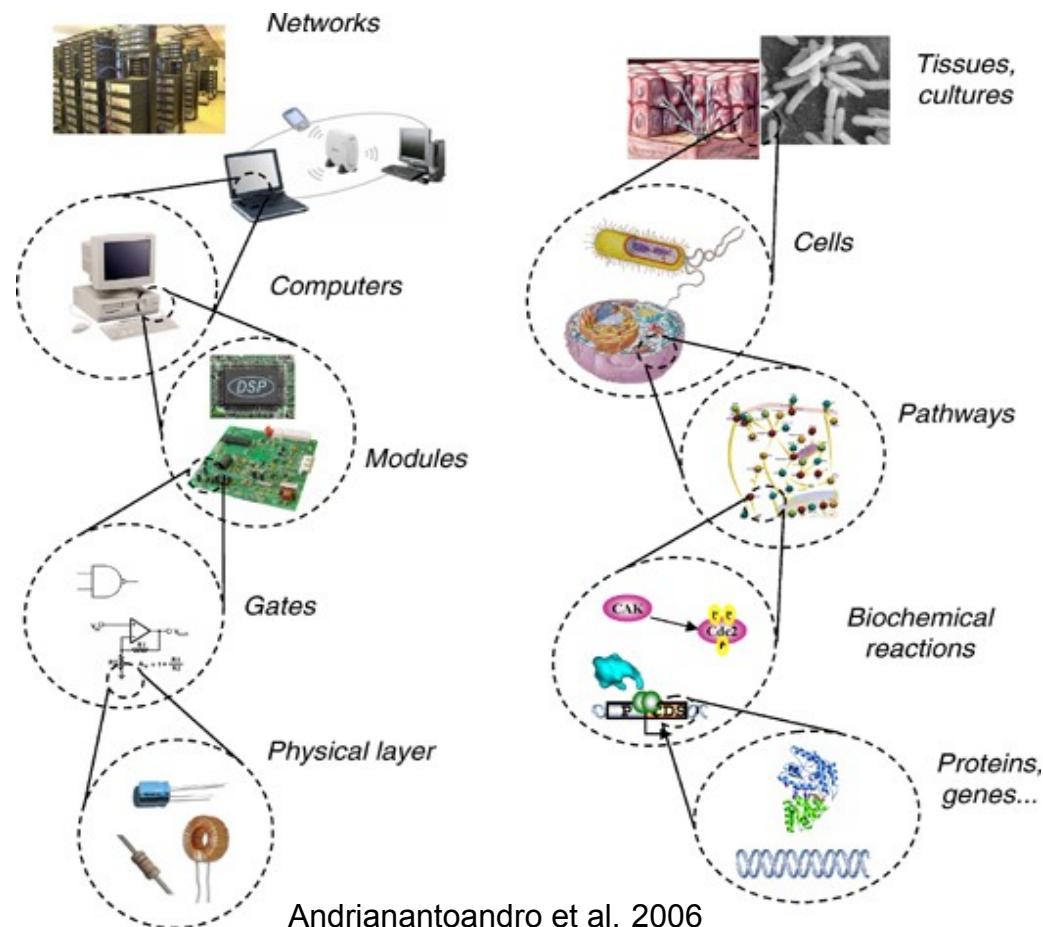


# Abstraction Principle

Abstraction

Standardisation

Quality Control





# Abstraction Principle

Abstraction

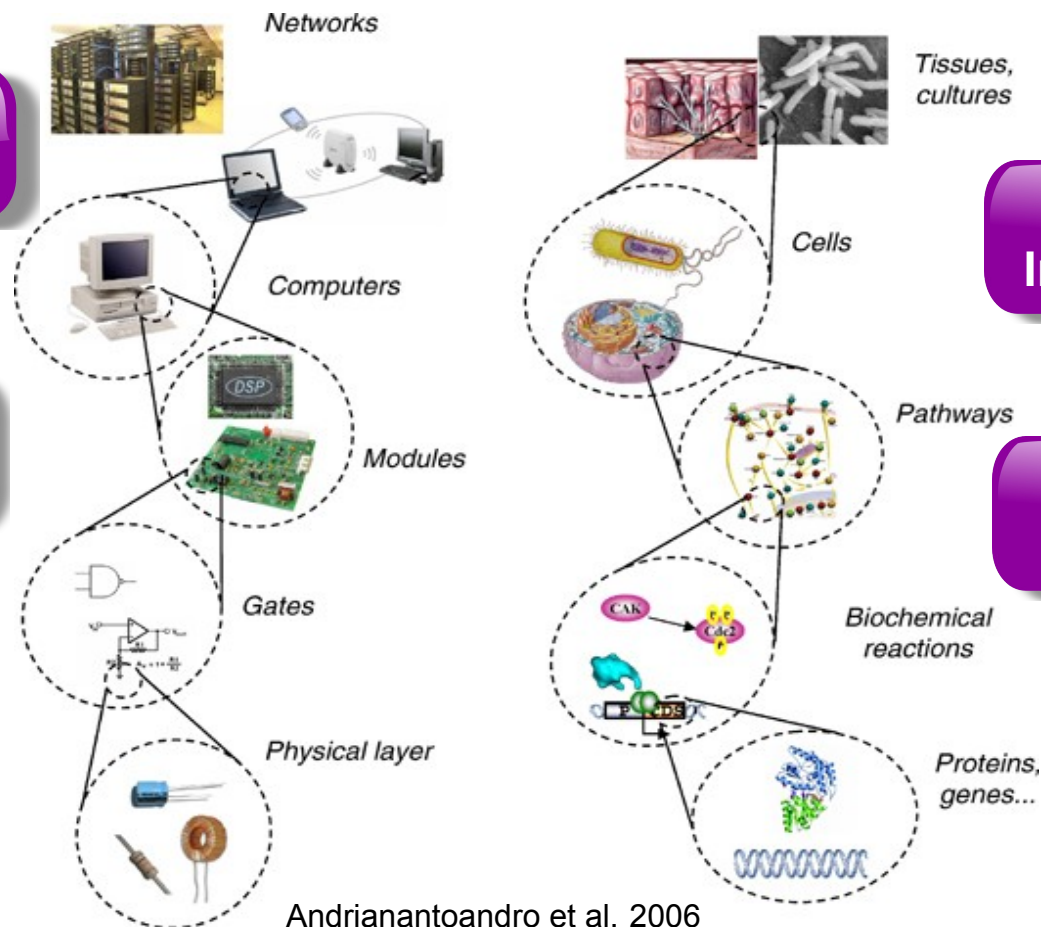
Standardisation

Quality Control

Break down  
complexity

Abstraction  
Hierarchy

Abstraction  
Layer



Modularity  
Inputs / Outputs

Decoupling

Andrianantoandro et al, 2006





# Abstraction Principle for SB



Abstraction

Standardisation

Quality Control

DNA

ACACTTCAAACCAAACCTTATTTCTAATTGAGAAGGGCCGGTTGA



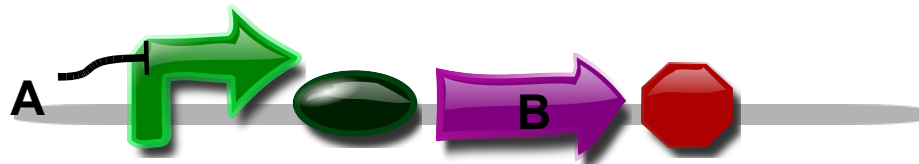
# Abstraction Principle for SB

Abstraction

Standardisation

Quality Control

Parts



DNA

ACACTTCAAACCAAACCTTATTTCTAATTGAGAAAGGGCCGGTTGA



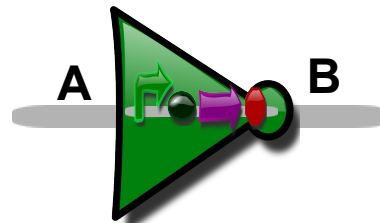
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Abstraction

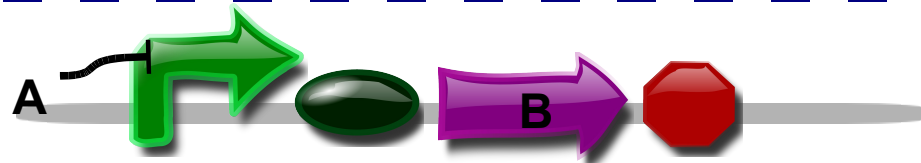
Standardisation

Quality Control

Devices



Parts



DNA

ACACTTCAAACCAAACCTTATTTCTAATTGAGAAAGGGCCGGTTGA



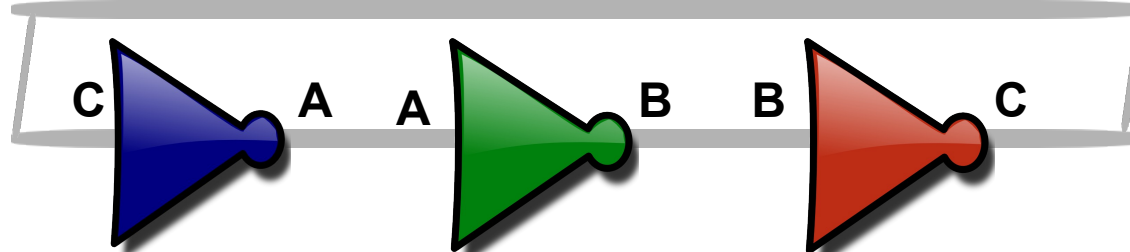
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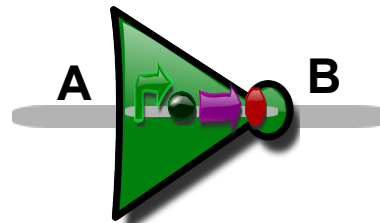
Standardisation

Quality Control

Systems



Devices



Parts



DNA

ACACTTCAAACCAAACCTTATTTCTAATTGAGAAGGGCCGGTTGA



# Standardisation Principle

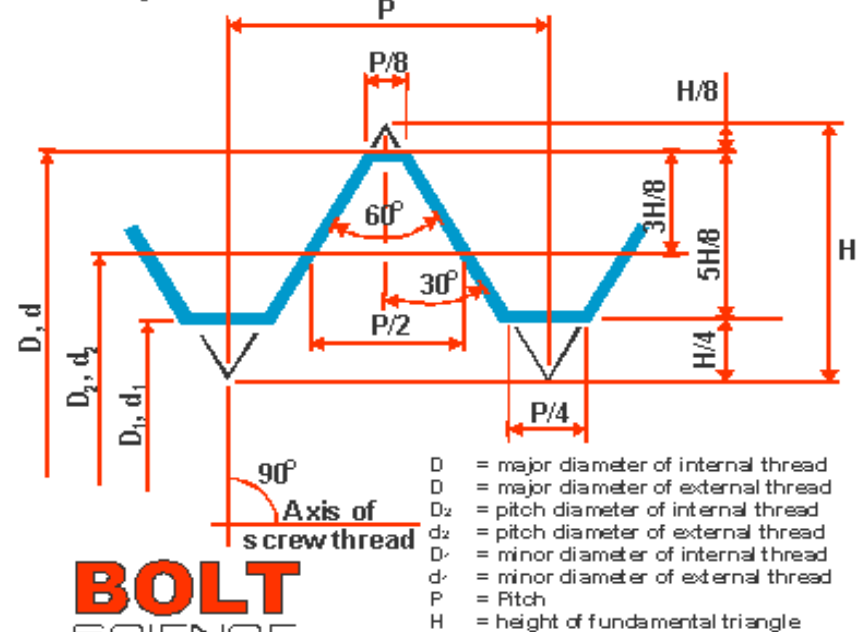
Abstraction

Standardisation

Quality Control



Basic profile of the Unified and ISO thread form





# Standardisation Principle

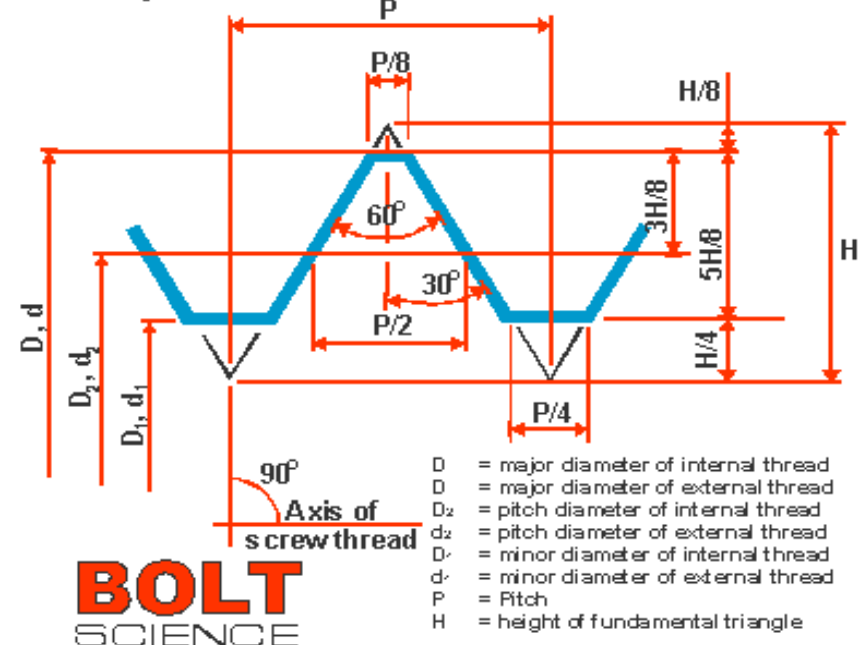
Abstraction

Standardisation

Quality Control



Basic profile of the Unified and ISO thread form



Uniform and agreed

Inter-operability

Re-usability

Economical Benefits



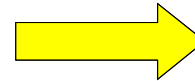
# Standardisation Principles for SB

Abstraction

Standardisation

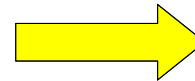
Quality Control

Standard Physical DNA composition



Topic 2

Standards Functional Composition

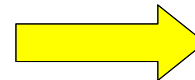


Topic 3

Standard Culture Conditions

Standard Measurements

Standard Cell Host (Chassis)



Topic 4

+ Practical



# Quality Control Principle

Abstraction

Standardisation

Quality Control

## PHOTODIODE

### Si PIN photodiode with preamp S6468 series

High-speed sensor with preamp

S6468 series is a high-speed photodetector consisting of a Si PIN photodiode and a preamplifier chip integrated in the same package. They feature high-speed response and high sensitivity over a wide spectral range from visible to near infrared light. The small package (TO-18) allows compact optical design. The amplifier input is at a virtual ground, so external noise which may appear when detecting high-speed signals can be suppressed.

#### Features

- Cut-off frequency ( $V_{cc}=5\text{ V}$ )  
S6468 : 15 MHz  
S6468-02: 35 MHz
- Low noise ( $f_c=1\text{ MHz}$ )  
S6468 : 25 nVrms/Hz<sup>1/2</sup>  
S6468-02: 28 nVrms/Hz<sup>1/2</sup>
- 3 pin TO-18 package
- Active area:  $\phi 0.8\text{ mm}$

#### Applications

- Optical fiber communication
- Video signal transmission
- Optical disk pick-up

#### Electrical and optical characteristics ( $T_a=25^\circ\text{C}$ , $V_{cc}=5\text{ V}$ , $R_L=500\ \Omega$ , $C_L=13\text{ pF}$ )<sup>1)</sup>

Parameter	Symbol	Condition	Min.	S6468 Typ.	Max.	Min.	S6468-02 Typ.	Max.	Unit
Spectral response range	$\lambda$			320 to 1080			320 to 1000		nm
Peak sensitivity wavelength	$\lambda_p$		-	800	-	-	800	-	nm
Photo sensitivity	S	$\lambda=650\text{ nm}$	-	13.5	-	-	8.5	-	mV/μW
		$\lambda=780\text{ nm}$	-	15.5	-	-	11	-	
		$\lambda=830\text{ nm}$	-	16.5	-	-	11	-	
Trans-impedance	$R_t$		-	30	-	-	20	-	kΩ
Power supply current	$I_{cc}$	$R_L=500\ \Omega$	-	-	3	-	-	3	mA
Output bias voltage <sup>2)</sup>	$V_o$	$R_L=500\ \Omega$ $P_{in}=0\ \mu\text{W}$	0.55	0.65	0.8	0.65	0.8	0.9	V
Temperature coefficient of output bias voltage	-		-	-2	-	-	-2	-	mV/°C
Cut-off frequency	$f_c$	$P_{in}=10\ \mu\text{W}$ <sup>3)</sup>	12	15	-	28	35	-	MHz
Maximum output voltage amplitude	-	Nonlinear distortion: 10% Max.	0.5	-	-	0.5	-	-	V <sub>p-p</sub>
Output impedance	$Z_o$	$f=5\text{ Hz}$	-	30	-	-	30	-	Ω
Output noise voltage	$V_n$	$P_{in}=0\ \mu\text{W}$ $f=1\text{ MHz}$	-	25	-	-	28	-	nV/Hz <sup>1/2</sup>
Overshoot	-	$P_{in}=10\ \mu\text{W}$ <sup>3)</sup>	-	-	10	-	-	10	%

#### Absolute maximum ratings

Parameter	Symbol	Min.	Max.	Unit
Power supply voltage <sup>1)</sup>	$V_{cc}$	-0.5	7	V
Power dissipation	P	-	300	mW
Operating temperature	$T_{opr}$	-20	70	°C
Storage temperature	$T_{stg}$	-40	150	°C

<sup>1)</sup> For definitions of  $R_L$  and  $C_L$ , refer to the basic connection.

<sup>2)</sup> Output voltage  $V_{out} = V_p(P_{in} \times S)$ .  $P_{in}$ : incident radiant flux (μW).

<sup>3)</sup> Peak value

<sup>4)</sup> A bypass capacitor (0.01 μF to 0.1 μF ceramic) is connected between the  $V_{cc}$  lead and the GND lead. The lead length should be less than 20 mm.

#### Recommended operating conditions

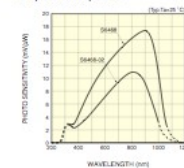
Parameter	Symbol	Min.	Typ.	Max.	Unit
Power supply voltage	$V_{cc}$	4.75	5	5.25	V
Load resistance	$R_L$	500	-	-	Ω
Load capacitance	$C_L$	-	-	13	pF
Operating temperature	$T_{opr}$	0	-	60	°C

SOLID STATE DIVISION

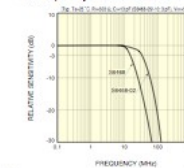
HAMAMATSU

## Si PIN photodiode with preamp S6468 series

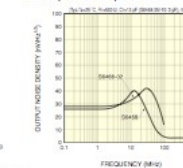
### Spectral response



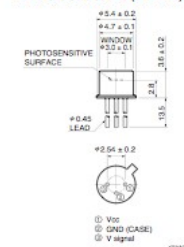
### Frequency characteristics



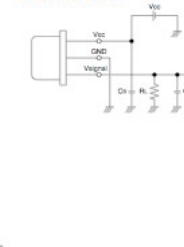
### Output noise spectrum



### Dimensional outline (unit: mm)



### Basic connection



### ESD

S6468 series may be damaged or their performance may deteriorate by such factors as electro static discharge from the human body, surge voltages from measurement equipment, leakage voltages from soldering irons and packing materials, etc. As a countermeasure against electro static discharge, the device, operator, work place and measuring jigs must all be set at the same potential. The following precautions must be observed during use:

- To protect the device from electro static discharge which accumulates on the operator or the operator's clothes, use a wrist strap or similar tools to ground the operator's body via a high impedance resistor (1 MΩ).
- A semiconductive sheet (1 MΩ to 100 MΩ) should be laid on both the work table and the floor in the work area.
- When soldering, use an electrically grounded soldering iron with an isolation resistance of more than 10 MΩ.
- For containers and packing, use of a conductive material or aluminum foil is effective. When using an antistatic material, use one with a resistance of 0.1 MΩ/cm<sup>2</sup> to 1 GΩ/cm<sup>2</sup>.

### Wiring

- $R_L$  and  $C_L$  are total resistive load and capacitive load viewed from the V signal terminal. When connecting a cable or circuit to the latter stage of the basic connection diagram, the cable or circuit resistance and capacitance should also be taken into account. They should be used in accordance with the recommended operating conditions:  $R_L=500\ \Omega$  and  $C_L=13\text{ pF}$ .
- A bypass capacitor ( $C_{in}=0.01\ \mu\text{F}$  to  $0.1\ \mu\text{F}$  ceramic) is connected between the  $V_{cc}$  lead and the GND lead.
- If electric current or voltage is applied in reverse polarity to an electronic device such as a preamplifier, this can degrade device performance or destroy the device. Always check the wiring and dimensional outline to avoid misconnection.

### Precautions for use

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Aug. 2003 DN

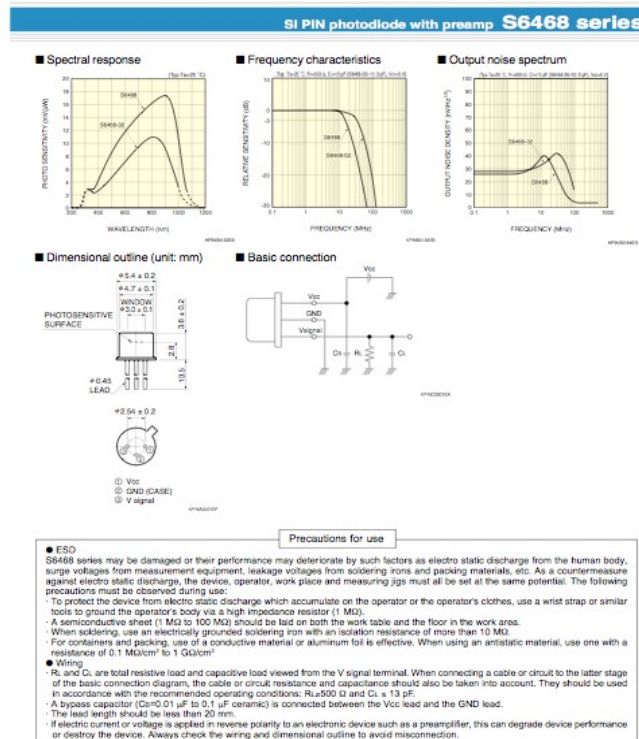
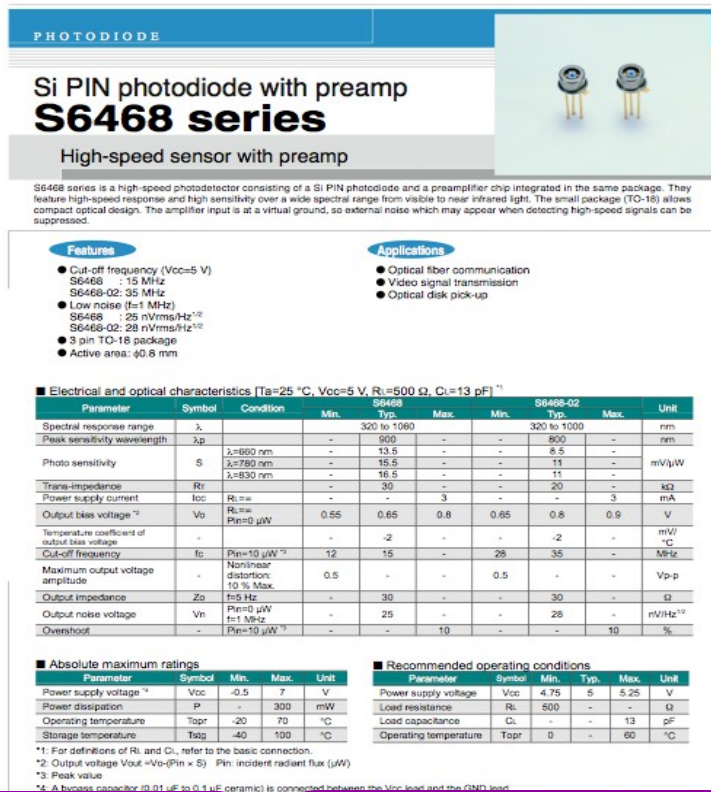


# Quality Control Principle

Abstraction

Standardisation

Quality Control



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Specification Sheet

Characterisation  
under Standard Conditions

Tolerances / Reliability

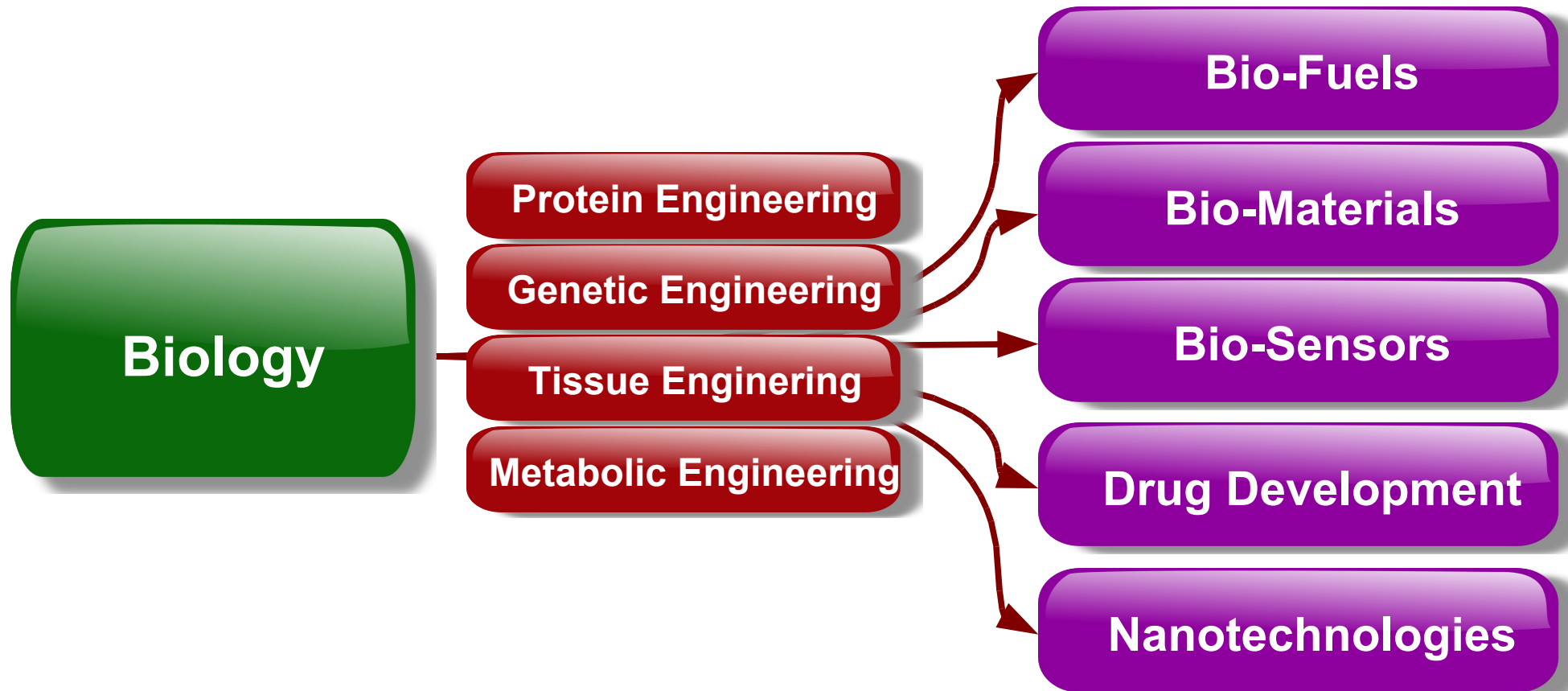
Trust





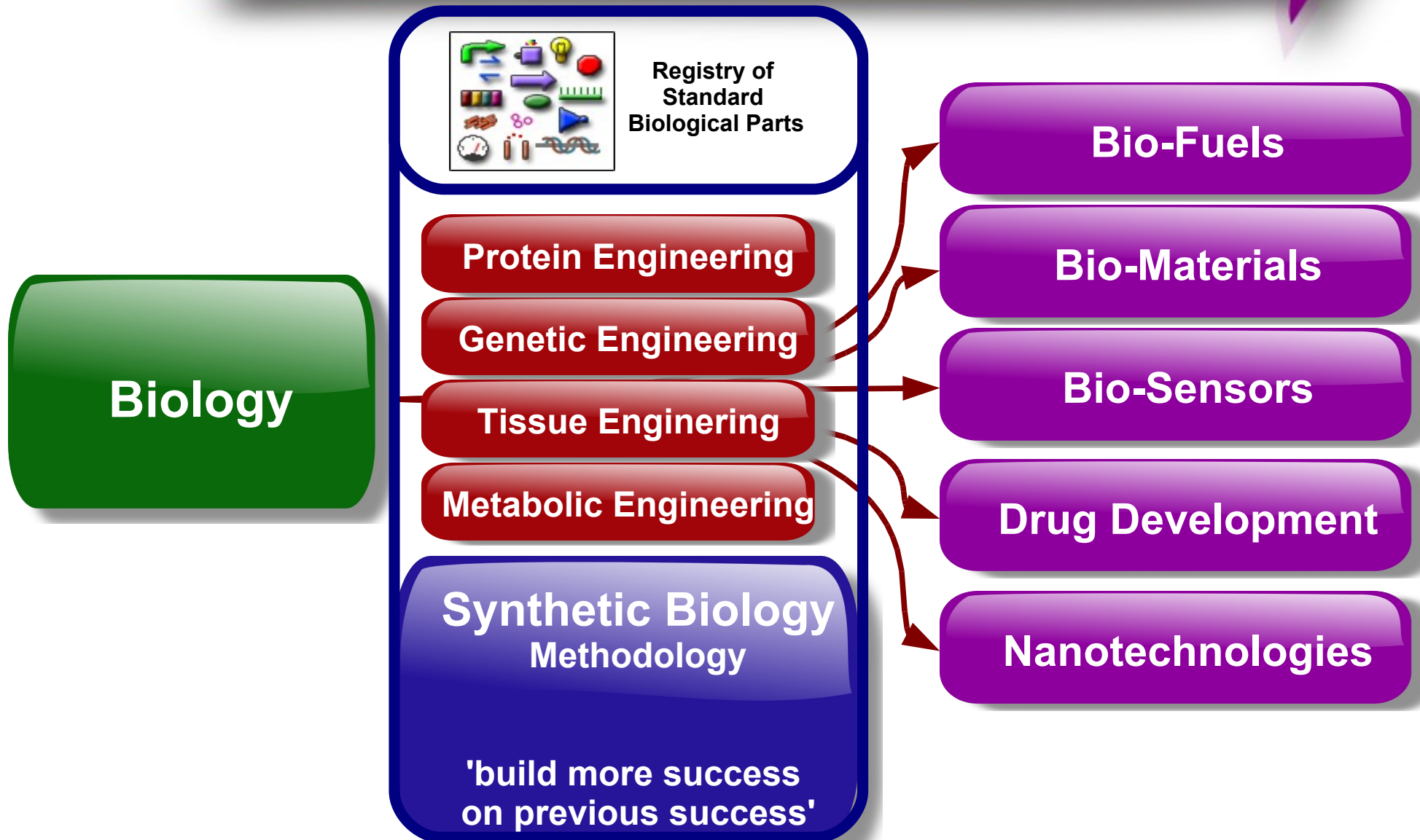


# Synthetic Biology Methodology





# Synthetic Biology Methodology







# But ....Engineering Challenges Ahead



**Growth  
Death**



**Diffusion  
Cross-Talk  
Noisy**



**Mutation  
Evolution**

**“What I cannot create, I do not understand.”**

**Richard Feynman (1918-1988)**

inspired by Austin Che's presentation





# Ethics and Society



**What will be the impact of  
making biology easier to engineer ?**

from Drew Endy's talk, Tianjin 2007





# Ethics and Society



**What will be the impact of  
making biology easier to engineer ?**

**More People**

**More Powerful  
DNA Programs**

**Faster  
Development**

from Drew Endy's talk, Tianjin 2007





# **Ethics and Society**

## **Resulting Issues**

**Bio Safety**

**Bio Security**

**Ownership, Sharing, Innovation**

**Ethics**

**Community**

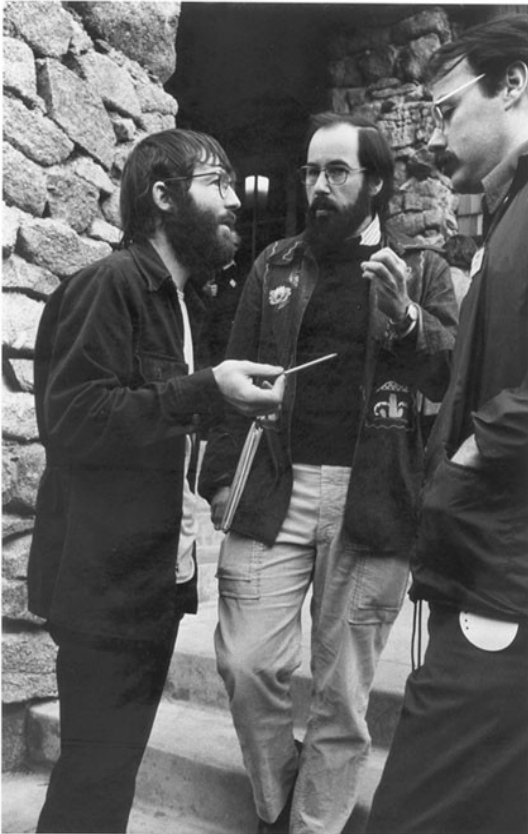
from Drew Endy's talk, Tianjin 2007



# Ethics and Society

## Asilomar (1975)

Recombinant DNA conference



## What has changed ?

1. Databases populated with sequence information.
2. The Internet
3. Early improvements in automated DNA construction technology.
4. Overnight shipping.
5. Expanded concern re: active misapplication of biotech.

from Drew Endy's talk, Tianjin 2007





# Ethics and Society



**Revitalise knowledge of biological safety**

**Avoid re-militarisation of biological technologies**

**Regardless, expect that technology will be misapplied. Prepare.**

**Develop an ownership & sharing framework that maximizes innovation and equity.**

**Build a community who can lead development of a constructive culture in Biological Engineering.**

from Drew Endy's talk, Tianjin 2007



# Synthetic Biology Community

**You are now part of it !!!**  
Engage ... Challenge ... Contribute

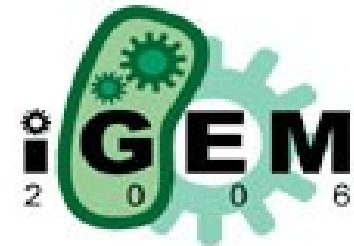




# References

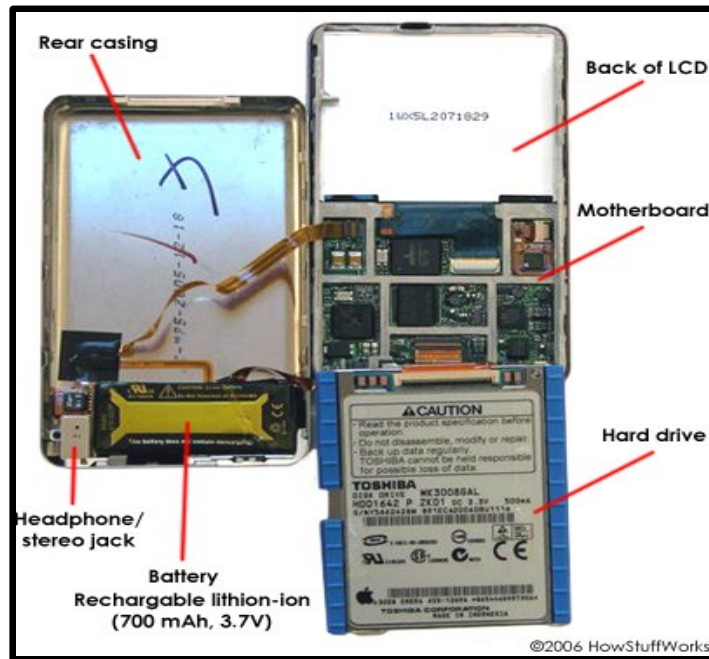


- > Drew Endy's Talks (on OWW)
- > Austin Che Presentations
- > OpenWetWare Folks
- > iGEM Competition
- > BioBricks Foundation





# Example: iPod



## Features:

Audio / Video / Photos  
External hard drive  
Calendar / Contacts  
Games  
Car Integration

